Functionality and nutritive value of composite plantain (*Musa Paradisiaca*) fruit and glandless cottonseed flours

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Abstract *Plantain* (Musa paradisiaca) *flours from fruits that are lyophilized, oven-dried, or vacuum oven-dried and hexane-defatted, contain an average of 2·9% protein, 0·7% fibre, 1·8% ash and 86·0% carbohydrate. Vitamins B_1, B_2, C, and niacin activity, and the minerals Ca, K, Mg, P and Fe, are present in good quantities. The oil extracted from the fruit contains mainly oleic, linoleic, linolenic and palmitic acids. The protein is a good source of isoleucine, leucine, lysine, and especially histidine. Alkaline and salt solutions extracted 2–3 times more protein than water; adding sodium dodecyl sulfate to the water produced similar proportions. The plantain flours perform poorly in functionality tests for emulsification, foamability, and water and oil absorption, but these properties are greatly improved when the flours are blended with glandless cottonseed flour. Nutritionally, tryptophan is the most limiting amino acid of the plantain flours. Plantain and cottonseed blends have improved compositions of isoleucine, leucine, lysine and histidine.*

Keywords: plantain, *Musa paradisiaca,* cottonseed, glandless cottonseed flour, oil, carbohydrate, proximates, vitamins, protein, vegetable protein ingredients, composite flour, drying methods, functionality, nutrition.

Introduction

Plantain (*Musa paradisiaca*) fruit, although a high starch (90%) and low protein (3·0%) food, has become an important commercial crop in many developing countries of tropical and subtropical regions of the world because plant breeders and agronomists have developed new, high yielding cultivars that respond well to improved planting methods, fertilizers and disease and insect controls (Irizarry *et al.* 1978, Tezenas Du Montcel 1979, Antonio 1980). In developing countries, e.g. Cameroon, Nigeria, Ghana, Liberia and Sierra Leone, plantain fruit, like its close relative the banana, is harvested at the unripe stage, then ripened prior to being consumed.

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The proximate composition, carbohydrate and protein components of green unripe and ripe plantain fruit were characterized by Ketiku (1973). The amounts of proteins and sugars in the fruit increase approximately one-half per cent and 16%, respectively, during ripening, while the quantity of starch decreases (Hernandez 1973, Ketiku 1973, Coursey *et al.* 1976, Madamba *et al.* 1977, Siade & Pedraza 1977, Awan & Ndubizu 1978, Fernandes *et al.* 1979). Plantain fruit is a good source of the vitamins, thiamine, riboflavin, niacin, and ascorbic acid, and the minerals, calcium, iron, phosphorus, magnesium, sodium, potassium, and silicon (Cintron & Cook 1932, Patil & Magar 1976, Padmaja & Koshy 1977, Tezenas Du Montcel 1979).

Plantain fruit is only grown in certain regions of developing countries and is transported under less than optimum conditions; it often arrives at processing plants and markets badly damaged, over-ripened and/or rotted. Foods prepared from over-ripened plantain fruit have a poor appearance and thus a lowered quality due to the caramelization of sugars and unwanted, sweet taste (Hernandez 1973). Studies have been conducted to determine green plantain fruit behaviour when stored under various conditions to aid in the development of the best method of prolonging its shelf life, without affecting overall quality and processing characteristics (Hernandez 1973, Ndubizu 1976, Siade & Pedraza 1977, Awan & Ndubizu 1978). Shelf-life of green plantain fruit may be successfully prolonged to 25 days at 30°C, and to 55 days at 12·8°C, when stored in sealed polyethylene bags containing a mould inhibitor and an ethylene absorbant. Ripe plantain fruits processed as cubes, chips or slices, and dried at temperatures of 50–75°C, or pureed, and then packed in polyethylene containers could be successfully stored for long time-periods under most temperature conditions (Wieneke & Achampong 1978, Delgado *et al.* 1979).

An economical method for the production of a storage-stable flour from green plantain fruit was developed by Rahman (1963). Plantain fruit was steam-peeled, sliced, soaked in citric acid, dried first at 93·3°C and then at 71°C in a cross circulation airflow oven for periods of 1 and 5 h, respectively, and then ground to a flour. The flour contained typically high starch and low protein concentrations and organoleptic taste tests established that the dried product was acceptable. Patil & Magar (1976) carried out a comparative study on chemical evaluation of banana powders prepared by vacuum oven and spray drying techniques. The results showed that, except for sugar, the vitamin and minerals studied together with protein, moisture, ash, and crude fibre were higher in spray-dried than in oven-dried flour. However, the vacuum oven-dried flour could be preserved for a longer period of time than the spray-dried material if stored in well-sealed containers.

Since plantain fruit is high in carbohydrate and low in protein, a possibility for modifying its composition and improving its quality is blending with vegetable products that are high in protein. This blending may improve plantain fruit's nutritional quality for use in developing countries where the people cannot afford animal products to meet their daily allowance of dietary protein. Rodriguez-Sosa *et al.* (1977a, 1977b) developed a flour from green banana and used it as a partial substitute for wheat flour in cupcakes that had good consumer acceptability. Ojofeitimi (1976) completed nutritional studies with rats on blends of cottonseed and soybean flours with purees of plantain, yam, and cassava. Based on protein efficiency ratios and efficiencies of nitrogen retention, the nutritional value of high starch-containing staple foods could be greatly improved nutritionally when blended with oilseed flour.

Materials and methods

Flour

Mature green plantain fruit was used as obtained from a supermarket in New Orleans, Louisiana. Peels were removed by hand and the fruit cut into thin slices (0·5–0·7 cm), divided into three portions, spread in trays and lyophilyzed, oven-dried (50°C) or vacuum oven-dried (50°C and 30 psi) overnight. After drying, each portion was defatted with n-hexane, air-dried for 24 h, and then ground into a 100-mesh flour. Most of the analyses were done on the oven-dried product, since on both a local and a commercial scale, it will probably be most representative of practical industrial plantain flour.

Hexane-defatted, glandless, cottonseed flour (100 mesh) was obtained from Rogers Delinted Cottonseed Co., Waco, Texas.

Compositional analyses

The following analyses were done in duplicate on flour produced by each method of drying. Determination of proximate and sugar composition of the flours was by the methods of the Association of Official Analytical Chemists (1975) and American Oil Chemists' Society (1976); total carbohydrate was calculated by difference. Amino acids were evaluated by gas-liquid chromatography (Kaiser *et al.* 1974). Fatty acids were examined by gas chromatography, while the atomic absorption spectrophotometric procedure was employed for the mineral analysis (American Oil Chemists' Society 1976). Vitamins were determined according to the method of the Association of Vitamin Chemists (1951). Chemical and amino acid scores of the flours were calculated according to FAO/WHO (1973). Gel electrophoresis was performed according to the method of Cherry *et al.* (1970).

Protein and nitrogen solubility

An equivalent gram of flour was suspended in a corresponding amount of liquid in a mortar and ground with a pestle for 10–15 min. The suspension was centrifuged at 23–25°C for 30 min at 43 500 × g. The supernatant was filtered through Whatman paper No. 4, and its pH was taken prior to protein quantitation.

Protein was extracted from the flours in deionized water, then in 0·015 N NaOH solution; in 0·034 N NaOH; in 10% NaCl; in 1% sodium dodecyl sulfate (SDS); and in 1% SDS, 10 mM dithiothreitol (DTT). The following ratios (w/v) were used: 1:4, 1:8, 1:12, 1:16, 1:20, 1:24, 1:32, and 1:40.

Table 1. Composition of plantain fruit dried by different methods, blends of the oven-dried hexane-defatted plantain flour with glandless cottonseed flour, and glandless cottonseed flour

Component*	Plantain flours (drying method)			Plantain:glandless cottonseed flour blends		Glandless cottonseed flour
	Lyophilized	Oven	Vacuum oven	1:3	1:1	
% of sample						
Moisture	8·17	5·75	11·53	7·49	6·91	8·07
Protein	3·09	3·06	2·56	42·16	29·13	55·19
Lipid	0·32	0·34	0·38	1·33	1·00	1·66
Crude fibre	0·73	0·66	0·68	0·43	0·51	0·35
Ash	1·78	1·88	1·79	5·88	4·55	7·21
Carbohydrate†	85·91	88·31	83·06	42·72	57·92	27·52
Free gossypol	—‡	—	—	0·053	0·035	0·07
Total gossypol	—	—	—	0·075	0·050	0·10
Free sugars:						
Fructose	0·91	1·87	2·27	0·47	0·94	—
Glucose	0·83	1·82	1·90	0·46	0·91	—
Sucrose	3·23	5·26	1·98	2·52	3·43	1·60
Raffinose	—	—	—	8·49	5·65	11·30
Stachyose	—	—	—	0·66	0·45	0·90

*Vitamins in oven-dried plantain flour were: A, 227 IU/lb; B_1, 41 μg%; B_2, 126 μg%; C, 133 000 μg%; and nicotinic acid, 1080 μg%. For glandless cottonseed flour, those same values were <227, 2106, 262·8, <1000, and 3335.
†Determined as difference of moisture, protein, lipid, crude fibre, and ash from 100; moisture of all flours ranged between 5·75% (oven-dried) and 11·53% (vacuum oven-dried).
‡None detected.

Protein solubility was determined for the water-flour suspension at pH levels adjusted by 1·0 units ranging from 2·0 to 11·0. The desired pH was attained by dropwise addition to the suspension of either 1 N HCl or 1 N NaOH with continuous stirring. In the solubility study, 1 g of flour was suspended in 80 ml of deionized water, adjusted to the desired pH, and allowed to stir for 20 min to solubilize the proteins. The suspension was centrifuged at room temperature for 30 min at 14 000 × g. Proteins were determined in duplicate by both the standard Kjeldahl method and the procedure of Lowry *et al.* (1951).

Emulsion capacity and viscosity

A 10% (2·5 g of flour in 25 ml of deionized water) suspension of the flour was made and adjusted to the desired pH. Oil-in-water emulsions were prepared as reported by McWatters & Cherry (1977). The breakpoint was considered as the point of oil-water-phase separation. The emulsion capacity was reported as ml of oil used per 25 ml of suspension. The emulsion viscosity was measured at 10 ml less than that required to reach the breaking point. The viscosity was measured with a number 5 spindle rotating at 2·5 rpm on a Brookfield Viscometer (Model RVT). All analyses were completed in triplicate at room temperature.

Table 2. Mineral composition of hexane-defatted flour of oven-dried plantain fruit, blends of oven-dried defatted plantain flour with glandless cottonseed flour, and glandless cottonseed flour

Mineral	Oven-dried plantain flour	Plantain:glandless cottonseed flour blends 1:3	Plantain:glandless cottonseed flour blends 1:1	Glandless cottonseed flour
% of flour				
Sulphur	0·050	0·493	0·350	0·640
Calcium	0·168	0·166	0·208	0·248
Potassium	0·058	1·457	1·325	1·590
Magnesium	0·119	0·078	0·092	0·064
Tin	0·179	0·045	0·085	—*
Silicon	0·089	0·057	0·068	0·046
Strontium	0·060	0·045	0·050	0·040
Phosphorus	0·146	1·240	0·878	1·610
Iron	0·048	0·054	0·052	0·056
ppm of flour				
Antimony	129·00	32·20	64·50	—
Silver	14·80	15·33	15·15	15·50
Molybdenum	0·46	0·22	0·30	0·14
Selenium	68·80	17·65	34·70	0·60
Zinc	9·39	9·46	9·44	9·48
Sodium	27·92	10·94	16·60	5·28
Manganese	7·46	6·32	6·70	5·94
Cadmium	186·80	46·72	93·41	0·026
Copper	1·72	1·49	1·57	1·41
Cobalt	30·00	7·50	15·00	—
Chromium	592·42	148·11	296·21	—
Mercury	0·0005	0·00042	0·00045	0·00039
Nickel	128·20	32·10	64·10	—

*Not determined.

Foam capacity, stability and viscosity

An aqueous suspension (2·5 g of flour in 50 ml deionized water) was adjusted to the desired pH, stirred for 15 min and then whipped for 6 min at number 8 speed on a Hamilton Beach Mixmaster. The contents were transferred to a graduated beaker, and foam volumes were measured. Foam capacity was calculated according to the method of McWatters & Cherry (1977). The stability was measured after allowing the foam to stand for 60 min. Foam viscosity was measured with the same viscometer as in the emulsion studies. All analyses were completed in triplicate at room temperature.

Water and oil absorption properties

To a 4·0 g flour sample in a 50 ml centrifuge tube, 20 ml of deionized water or cottonseed oil was added and stirred periodically for 60 min. The tube was centrifuged for 15 min at

Table 3. Fatty acid composition of oil in plantain fruit dried by different methods and glandless cottonseed kernels

Fatty acid (% of oil)	Plantain fruit (drying method)			Glandless cottonseed kernels
	Lyophilized	Oven	Vacuum oven	
Lauric (C12:0)	0·38	0·23	0·20	0·10
Myristic (C14:0)	0·52	0·36	0·29	1·00
Palmitic (C16:0)	40·60	28·32	27·05	27·78
Palmitoleic (C16:1)	3·03	2·48	2·24	1·11
Stearic (C18:1)	2·09	1·76	1·54	3·02
Oleic (C18:1)	9·07	7·16	6·33	19·12
Linoleic (C18:2)	29·09	37·11	39·02	46·60
Linolenic (C18:3)	11·86	19·14	19·56	0·10
Arachidic (C20:0)	0·42	0·47	0·48	0·41
Gadoleic (C20:1)	—*	0·15	0·16	—
Eicosadienoic (C20:2)	—	0·06	0·11	—
Behenic (C22:0)	0·38	0·55	0·70	—
Erucic (C22:1)	—	0·34	0·39	0·65
Lignoceric (C24:0)	1·22	0·91	0·93	0·10
Hexacosanoic (C26:0)	1·33	0·95	1·00	—

*Trace or none detected.

43 500 × g. The remaining liquid was decanted and measured. The amount of water or oil remaining in the flour was determined by difference and defined as absorption capacity. The analyses were completed in triplicate at room temperature.

Results and discussion

Composition

Proximate, free sugar, and vitamin composition of lyophilized, oven-dried, and vacuum oven-dried plantain fruit, hexane-defatted glandless cottonseed flour, and blends of hexane-defatted flours from the oven-dried plantain fruit and cottonseed flour are presented in Table 1. Plantain fruit dried by different methods shows no major variation in composition; average proximate values for the three dried products were 2·9% protein, 0·35% lipid, 0·69% crude fibre, 1·82% ash, and 86·0% carbohydrate. Differences were mainly attributable to moisture content.

Compared with the glandless cottonseed flour used in these studies, plantain fruit is low in protein (2·56–3·09% versus 55·19%) and ash (1·78–1·88% versus 7·21%), and high in crude fibre (0·66–0·73% versus 0·35%) and carbohydrate (83·06–88·31% versus 27·52%). Plantain fruit has very little oil residue and contains less than that of cottonseed flour after hexane-defatting. The free sugars of plantain fruit are mainly fructose, glucose, and sucrose, whilst those of cottonseed flour are sucrose, stachyose, and

Table 4. Amino acid composition of hexane-defatted flour of plantain fruit dried by different methods, blends of the oven-dried plantain flour with glandless cottonseed flour, and glandless cottonseed flour

Amino acid (% of total amino) acids recovered)*	Plantain flours (drying method)			Plantain:glandless cottonseed flour blends		Glandless cottonseed flour
	Lyophilized	Oven	Vacuum oven	1:3	1:1	
Alanine	4·64	4·69	5·37	4·17	4·19	4·17
Valine	4·64	4·69	4·55	4·36	4·37	4·35
Glycine	5·06	4·69	4·96	4·36	4·37	4·35
Isoleucine	3·80	3·91	3·72	3·07	3·08	3·05
Leucine	6·75	6·25	6·61	6·13	6·15	6·14
Proline	3·80	3·91	4·13	3·79	3·70	3·71
Threonine	4·22	3·91	3·72	3·35	3·36	3·35
Serine	8·44	12·50	14·88	4·89	5·10	4·77
Methionine	0·84	0·78	1·24	1·29	1·26	1·30
Phenylalanine	4·64	4·69	4·55	5·44	5·45	5·47
Aspartic acid	16·03	13·28	12·40	9·97	10·07	9·93
Glutamic acid	11·39	11·72	10·33	20·99	20·76	21·17
Tyrosine	2·11	1·95	2·07	3·26	3·22	3·27
Lysine	5·06	5·08	5·37	4·76	4·72	4·70
Histidine	12·24	10·94	9·50	3·38	3·64	3·27
Arginine	4·64	5·08	5·37	15·12	14·85	15·13
Cystine/2	0·84	0·78	0·83	1·75	1·71	1·76
Tryptophan	—†	—	—	1·14	0·77	1·53

*Total amino acids recovered: lyophilized, 2·37 g/100 g sample; oven-dried, 2·56; vacuum oven-dried, 2·42; plantain flour:glandless cottonseed flour blends, 1:3, 41·95, 1:1, 29·04; glandless cottonseed flour, 55·54.
†Detected <0·1%.

especially raffinose. Plantain fruit is especially high in vitamin C but contains less B_{12}, B_2 and nicotinic acid than cottonseed flour. Blends of the two ingredients (1:3, 1:1; plantain flour: cottonseed flour; w:w) provide products that contain the quality features of both sources.

Although oven-dried plantain flour is lower in calcium, potassium, phosphorus and iron than cottonseed flour, it is a better source of magnesium, manganese, and copper (Table 2); plantain fruit is also particularly high in antimony, selenium, cadmium, chromium and nickel. The blends reflect the good mineral composition of both products.

Unsaturated fatty acids accounted for most of the oil composition of plantain fruit (Table 3); depending on the drying method, oleic, linoleic, and linolenic acids combined represented 50·02% to 64·1% of the oil. Plantain oil was also high in saturated palmitic acid (27·05% to 40·60%). The oil of the lyophilized-dried fruit had higher palmitic acid and less of the unsaturated fatty acids and minor long-chain components, gadoleic, eicosadienoic and erucic acids, than those from the oven- and vacuum oven-dried samples. The palmitic acid content of the latter two samples was comparable with that of cottonseed oil. Oil from plantain fruit has less oleic acid and much more long-chain fatty acids (C20–C26) than cottonseed oil (Cherry, 1983).

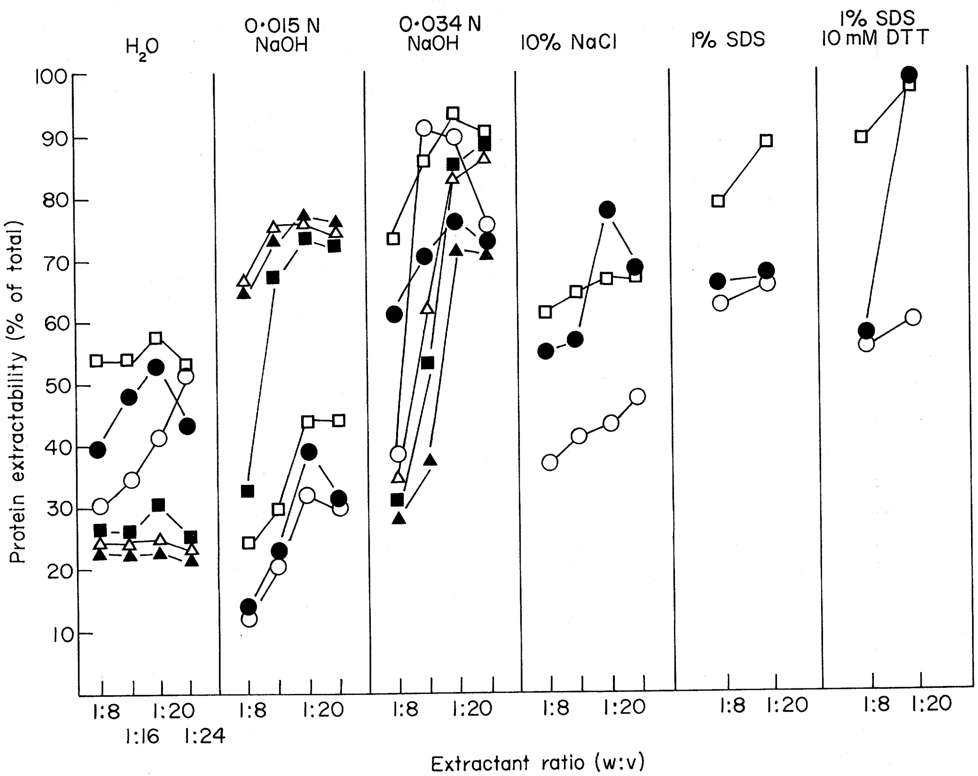

Figure 1. Extractability of proteins (% of total protein; Kjeldahl N × 6·25) in hexane-defatted flours of plantain fruit dried by different methods, blends of oven-dried plantain flour with glandless cottonseed flour, and glandless cottonseed flour. Plantain flour: ○ = lyophilized; ● = oven-dried; □ = vacuum oven-dried. Oven-dried plantain-cottonseed blends: ■ = 1:3; △ = 1:1; ▲ = cottonseed flour.

Amino acids in plantain fruit proteins were generally unaffected by the drying method used (Table 4). Application of heat during the drying process lowered the content of threonine, aspartic acid and histidine when compared with those of the lyophilized sample; the vacuum oven-dried flour had higher methionine content than those dried by the other two methods. Compared with cottonseed flour protein, the protein from plantain products had better essential amino acid composition; although plantain flour protein is lower in the sulphur-containing amino acids, phenylalanine, and tyrosine. Values of serine, aspartic acid and histidine are much higher in protein from plantain flours than in the cottonseed product. Cottonseed flour protein has much more glutamic acid and arginine than that from plantain flours. The blends reflect the quality features of both flours.

Protein extractability, gel electrophoretic properties, and solubility

Figures 1 and 2 present data showing the extractability of proteins from defatted plantain and glandless cottonseed flours and their blends at various ratios (1:8, 1:16, 1:20 and 1:24;

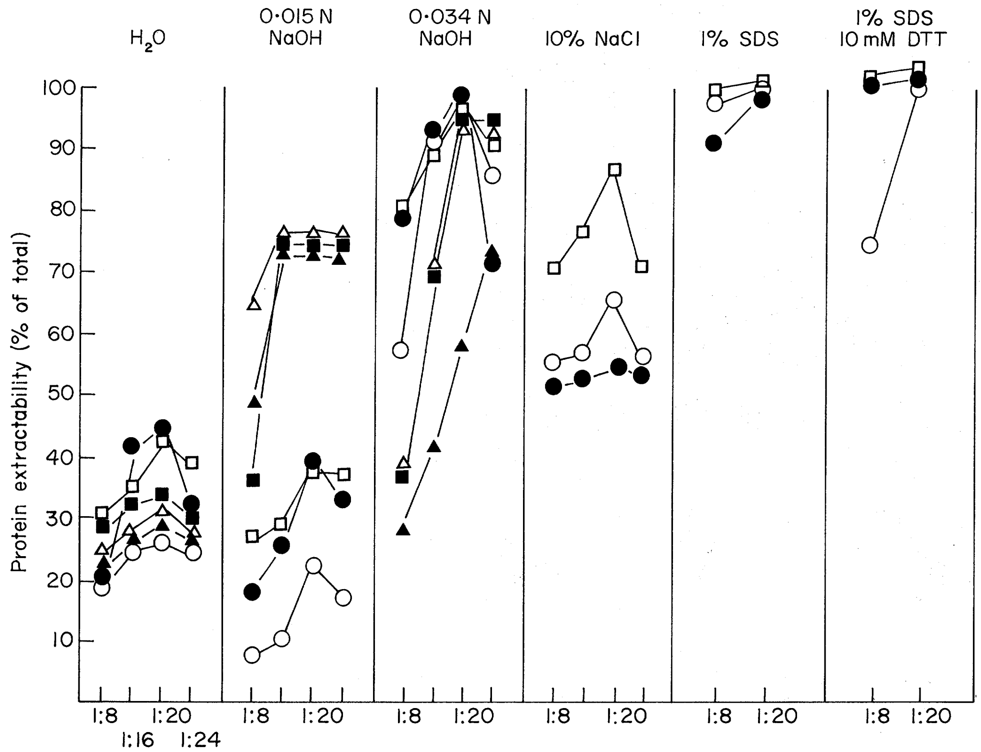

Figure 2. Extractability of proteins (% of total; Lowry *et al.* 1951) in hexane-defatted flours of plantain fruit dried by different methods, blends of oven-dried plantain flour with glandless cottonseed flour, and glandless cottonseed flour. Plantain flour: ○ = lyophilized; ● = oven-dried; □ = vacuum oven-dried. Oven-dried plantain-cottonseed blends: ■ = 1:3; △ = 1:1; ▲ = cottonseed flour.

flour:extractant; w:v), and with different extractants, including water, 0·015 N NaOH, 0·034 N NaOH, 10% NaCl, 1% SDS, and 1% SDS plus 10 mM DTT. The percentage of total protein extracted by each extractant was determined by the methods of Kjeldahl (N × 6·25) and Lowry *et al.* (1951). In most cases, the 1:20 ratio extracted maximum quantities of proteins.

Electrophoretic gel patterns show that proteins extracted from plantain fruit flour with water, 0·015 NaOH or 0·034 N NaOH were similar (Figure 3). One major (dark staining) and many minor (light staining) proteins were noted. Because of the high concentration of water-extractable proteins in cottonseed flour, the plantain components do not show in the blended samples; except for quantitative variations in certain bands, these patterns resemble that of cottonseed flour.

More of the protein was soluble in water than in 0·015 N NaOH. The 0·034 N NaOH extracted between 90% and 100% of the plantain protein. Composition of 10% NaCl solutions varied between those of the 0·015 N NaOH and 0·034 N NaOH extractions. Adding SDS, or SDS plus DTT, to water improved the extractability of plantain proteins. These latter data suggest that to extract proteins from plantain fruits efficiently, the

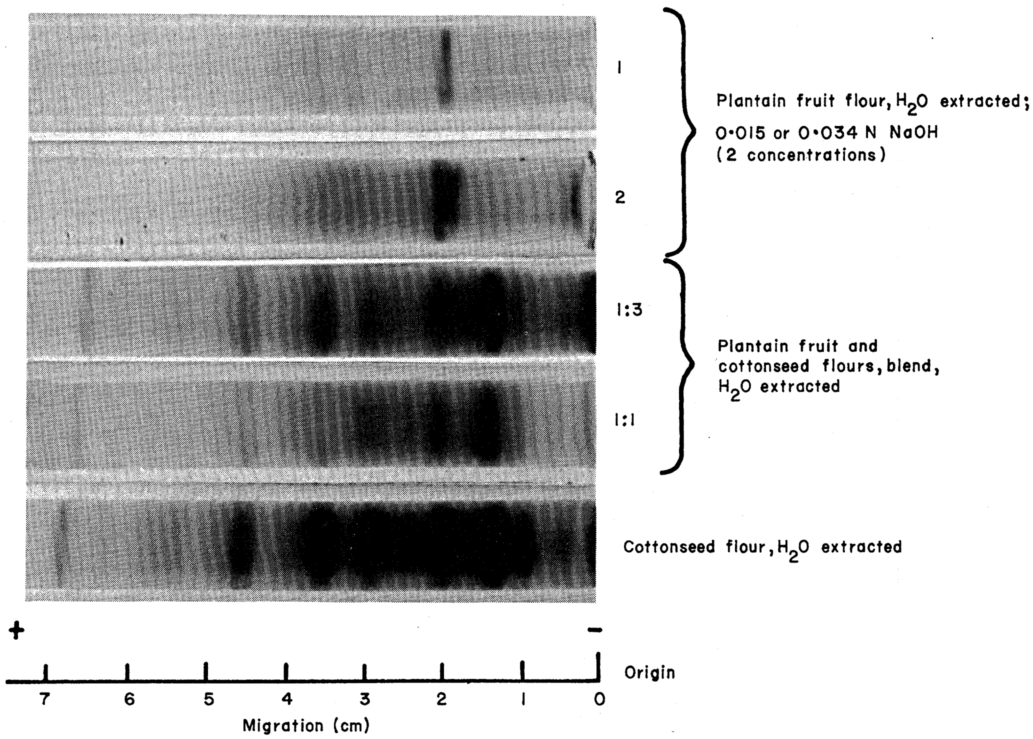

Figure 3. Typical polyacrylamide disc gel electrophoretic patterns of proteins in water and 0·015 and 0·034 N NaOH fractions of plantain fruit flour (two concentrations), cottonseed flour, and their blends (1:1, 1:3, cottonseed: plantain fruit flours; w:w).

membrane structures of the cells in the flour need to be disrupted (Cherry & Prescott 1974). Many of these components may be proteins and/or enzymes bound to membrane structures.

The solubility curves of proteins determined by the methods of Kjeldahl analysis and Lowry *et al.* (1951) in plantain flours, dried by different methods, showed isoelectric points at or near pH 5·0 (Figure 4). Based on the Kjeldahl analysis, highest solubility was noted between pH 8.0 and 11.0 for proteins of flours from lyophilized and vacuum oven-dried plantain fruit; solubilities reached a level of 100% between pH values 9 and 11. Proteins in the oven-dried flour did not attain this same high level of solubility (the highest value was 74·2% at pH 11)—as did the other two plantain flours. The solubility of proteins in oven-dried flour, as determined by the Lowry *et al.* (1951) method, was equally high at pH 2 and 11 and comparable with the values of the lyophilized product. The vacuum oven-dried sample exhibited increasing protein solubility as determined by the Lowry *et al.* (1951) method between pH values 5 and 11.

Glandless cottonseed flour evaluated for protein extractability at pH values ranging from 2 to 11 by the Kjeldahl and Lowry *et al.* (1951) methods had typical protein solubility curves (Cherry & Leffler 1984). Similar curves to those of glandless cottonseed flour were noted for the blends of the fruit and seed products.

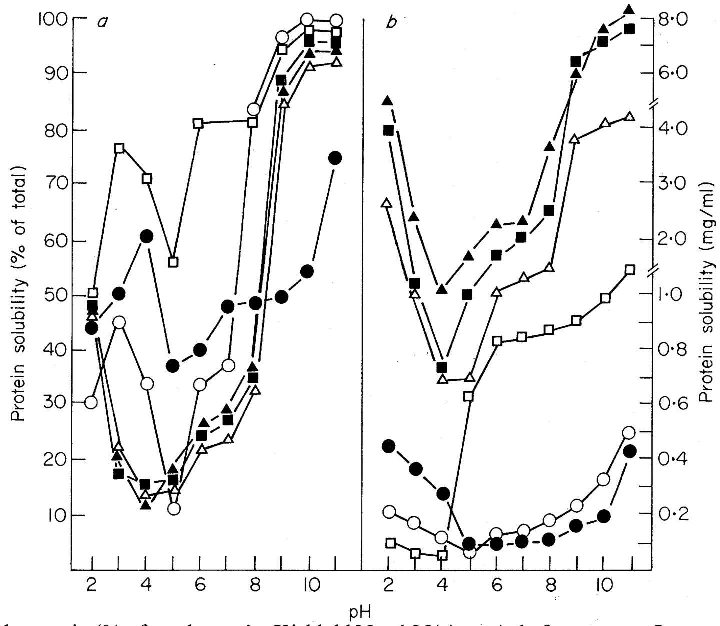

Figure 4. Soluble protein (% of total protein, Kjeldahl N × 6·25(*a*); mg/ml of extractant, Lowry *et al.* 1951(*b*)) in aqueous extracts at various pH values of hexane-defatted flours of plantain fruit dried by different methods, blends of the oven-dried plantain flour with glandless cottonseed flour, and glandless cottonseed flour. Plantain flour: ○ = lyophilized; ● = oven-dried; □ = vacuum oven-dried. Oven-dried plantain-cottonseed blends: ■ = 1:3; △ = 1:1; ▲ = cottonseed flour.

Emulsion capacity and viscosity

The emulsion capacities of plantain flours prepared by lyophilized, oven-, and vacuum oven-dried methods increased as the pH of the suspensions containing these products was raised from 2·5 to 8·0 (Figure 5). Although all of the plantain flours formed thin, salad dressing-type, emulsions, those of the lyophilized flours were much thinner than the other two products. The poor functionality of the plantain flours is probably due to their low protein content. Quantity and quality of proteins in vegetable protein products were shown to play key roles in functionality (Cherry & Leffler 1984). The emulsion capacities of the glandless cottonseed flour followed a similar curve to that of protein extractability (compare Figures 2 and 5); i.e. high at pH 2·0, dropping to a low value at the isoelectric point, pH 5.0, and then increasing at pH values of 6·5 and 8·0. The 1:1 blend also followed the pattern of the protein solubility curve, but at a lower level than that of the cottonseed flour, and the decrease in emulsion capacity at pH 8·0 that was noted to be only slight in the latter flour, was distinct with this mixture. At pH 2·5, the 1:3 blend had the highest capacity (59·2 ml of oil) of all samples examined in this study at the various pH values.

Highest emulsion viscosities for the plantain flours prepared by lyophilization and vacuum oven drying were at pH 2·5; the highest value for the oven-dried sample was at pH 5·0. The viscosities of all treatments declined at pH values 6·5 and 8·0. The emulsions of glandless cottonseed flour and the blends were more viscous than the plantain flour

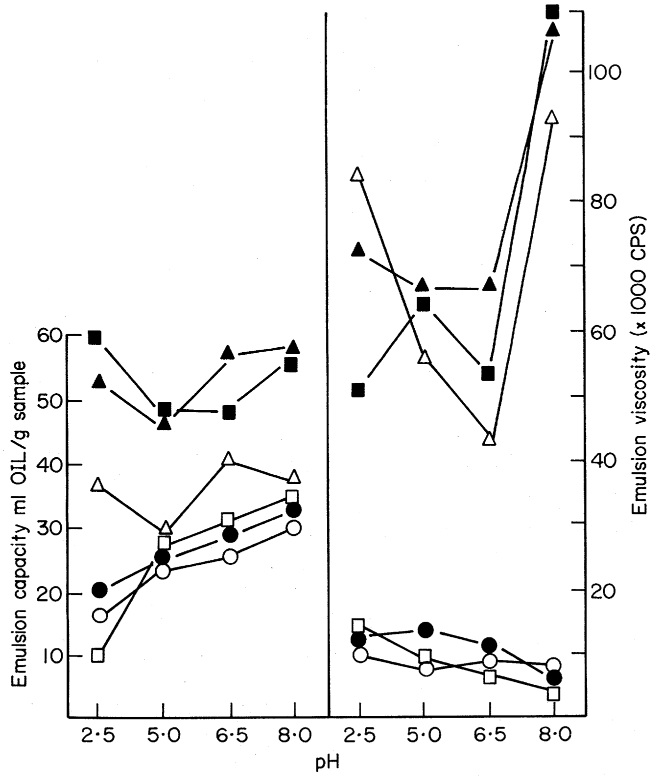

Figure 5. Emulsifying properties of aqueous suspensions at various pH values of hexane-defatted flours of plantain fruit dried by different methods, blends of the oven-dried plantain flour with glandless cottonseed flour, and glandless cottonseed flour. Plantain flour: ○ = lyophilized; ● = oven-dried; □ = vacuum oven-dried. Oven-dried plantain-cottonseed blends: ■ = 1:3; △ = 1:1; ▲ = cottonseed flour.

emulsions and exhibited the highest viscosities at pH values 2·5 and 8·0. The blends had their lowest values at pH 6·5, while that of the cottonseed flour was similarly low at pH values 5·0 and 6·5.

Foam capacity, stability and viscosity

Compared with glandless cottonseed flour, suspensions of the three plantain products formed very thin, unstable and low viscosity-type foams (Figure 6). They all formed large bubble-type foams that collapsed from 55% to 100% during the 60 min stability test. The low protein content of the plantain flours probably contributed to their inability to form stable foams (Cherry & Leffler 1984). Adding cottonseed flour to the oven-dried plantain product vastly improved the foaming properties. Values of the blends were similar to or better than those of the cottonseed flour. This was particularly noted with the foam volume increase of both blends at pH 6·5, the foam stability of the 1:3 blend at pH values 5·0, 6·5 and 8·0, and the foam viscosities of both blends at pH 6·5.

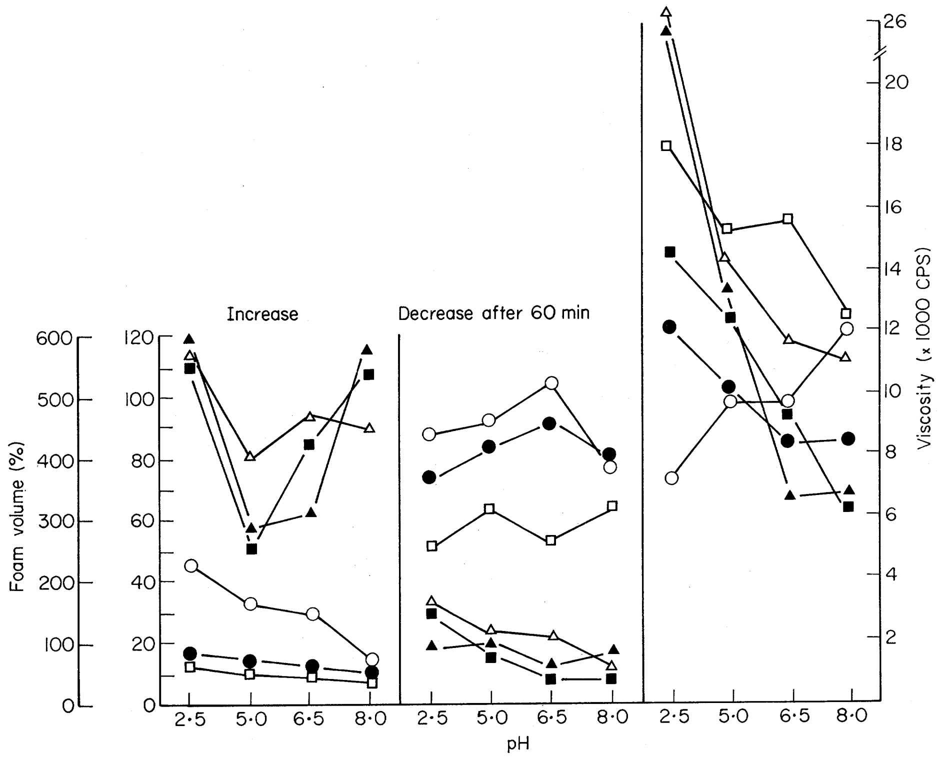

Figure 6. Whippability properties of aqueous suspensions at various pH values of hexane-defatted flours of plantain fruit dried by different methods, blends of the oven-dried plantain flour with glandless cottonseed flour, and glandless cottonseed flour. Plantain flour: ○ = lyophilized; ● = oven-dried; □ = vacuum oven-dried. Oven-dried plantain-cottonseed blends: ■ = 1:3; △ = 1:1; ▲ = cottonseed flour.

Table 5. Water and oil absorption of hexane-defatted flours of plantain fruit dried by different methods, blends of the oven-dried plaintain flour with glandless cottonseed flour, and glandless cottonseed flour

Solution (ml/gm)	Plantain flours (drying method)			Plantain:glandless cottonseed flour blends		Glandless cottonseed flour
	Lyophilized	Oven	Vacuum oven	1:3	1:1	
Water	1·1	0·89	0·93	0·95	0·70	1·00
Oil	1·3	1·10	0·93	1·25	1·00	1·51

Water- and oil-absorption capacity

Water- and oil-absorption capacities of the flour from lyophilized plantain fruit were slightly higher than those prepared by the heat drying procedures (Table 5). The absorption capacities of the lyophilized flour were similar to those of the glandless cottonseed product. Blending of the oven-dried plantain flour with cottonseed flour at a ratio of 1:3 caused the capacities to fall between those of the two individual products. The 1:1 blend had absorption capacities that were less than those of the two individual flours.

Table 6. Nutritive quality of hexane-defatted flours of plantain fruit dried by different methods, blends of the oven-dried plantain flour with glandless cottonseed flour, and glandless cottonseed flour

Amino acid	Plantain flours (drying method)			Plantain:glandless cottonseed flour blends		Glandless cottonseed flour
	Lyophilized	Oven	Vacuum oven	1:3	1:1	
Valine	71·20	78·60	85·80	86·40	85·80	86·20
Isoleucine	72·75	81·75	87·75	76·00	75·50	75·75
Leucine	74·02	74·88	89·17	86·88	86·31	87·03
Lysine	70·72	77·27	92·17	84·54	84·36	84·72
Threonine	81·00	81·75	87·75	83·00	77·25	83·00
Tryptophan	<32·39	<32·75	<39·02	49·85	147·64	154·02
Cystine-methionine	37·14	37·42	55·71	86·00	83·42	86·57
Tyrosine-phenylalanine	86·35	92·69	104·02	143·65	142·03	144·36
Most limiting amino acid	Tryptophan	Tryptophan	Tryptophan	Tryptophan	Isoleucine	Isoleucine
Chemical score	<32·39	<32·72	<39.02	49·85	75·50	75·75

Amino acid score and chemical score were calculated according to FAO/WHO (1973).

Nutritional properties

Plantain fruit flour is low in oil and protein, but is high in carbohydrate, minerals and vitamins (Table 1). Although the protein content of the flour is low, its essential amino acids make it a good food ingredient in blends with vegetable protein products, such as those that can be developed from cottonseed. Studies with rats to evaluate the nutritional quality of African staple foods, including dried plantain and banana products supplemented with vegetable proteins of cottonseed and soybean, have been conducted by Ojofeitimi (1976) and Velu *et al.* (1978). It was concluded that several cottonseed and soybean combination products had promise as dietary supplements to improve the protein portion of diets in developing countries. These products may have flavour characteristics that will make them especially desirable to certain populations. Concern was expressed about problems that may arise during processing of these fruits to dried products which may render their amino acids unavailable nutritionally. The research presented herein on the production of either lyophilized, oven-dried, or vacuum oven-dried flours from plantain fruit shows that loss of protein quality, including amino acid content, is minimal during these drying processes.

The nutritional quality of plantain flours, blends and cottonseed flour (as shown by the amino acid and chemical scores) is presented in Table 6. The first and second limiting amino acids in the plantain flours are tryptophan and the combined sulphur-containing amino acids, cystine and methionine, respectively; similar results were published by Ketiku (1973). Since tryptophan, cystine and methionine are the most limiting amino acids in plantain flour, maximum benefit from this product as a protein source would be obtained by direct supplementation with these amino acids or blending with vegetable protein ingredients such as cottonseed (Table 6, Berardi & Cherry 1979). The higher isoleucine level in plantain flour than in cottonseed flour can be used as a basis for improving the deficiency in the latter's products; isoleucine is the limiting amino acid in cottonseed.

Histidine is an essential amino acid for infants (Young & Scrimshaw 1977), and the possibility that histidine is equally essential for normal adults has also been suggested (Kopple & Swendseid 1974). Thus, the extremely high content of histidine in plantain flour contributes to the use of this product in food formulations, especially those for infants. Composites with cottonseed protein products, or those of other endemic seed sources such as egusi (*Colocynthis citrullus* L.), would add to the potential of new foods for developing countries (Akobundu *et al.* 1982, Cherry & Leffler 1984).

Plantain fruit which has been dried by either lyophilization, oven drying, or vacuum oven drying, and hexane-defatted to remove oil which contains high percentages of polyunsaturated fatty acids which could cause off-flavours when oxidized, should remain stable during storage for long time periods, and be easily transported to processing plants and the market place for use as food ingredients. Although the plantain flours performed poorly in various functionality tests, this problem can be resolved by blending these products with a vegetable protein ingredient such as cottonseed flour. These results plus certain nutritional features further support the contention that dried ingredients of plantain fruit have the potential of being used as foods.

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